Effects of dietary crude protein and supplemental urea levels on nitrogen and phosphorus utilization by feedlot cattle[1]

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ABSTRACT: Three dietary CP concentrations (11.5, 13.0, and 14.5% of DM) and 3 supplemental urea levels (100, 50, and 0% of supplemental N) were used in a completely randomized block design experiment conducted at 2 locations to determine N and P balance and serum urea N (SUN) concentrations of feedlot cattle. Crossbred steers [British and British × Continental; initial BW = 315.0 ± 3.2 kg at location 1 (n = 27) and initial BW = 353.2 ± 8.4 kg at location 2 (n = 27)] were used in 3 nutrient balance sampling periods (SP) at the beginning, middle, and end of the feeding period (154 d in location 1 and 159 d in location 2). Fecal N (g/d; $P = 0.03$), urinary N (g/d; $P < 0.01$), urinary urea N (UUN; g/d; $P < 0.01$), apparent N absorption (g/d; $P < 0.01$), and SUN concentration (mg/dL; $P < 0.01$) increased linearly as dietary CP concentration increased. Nitrogen retention (g/d) was not affected ($P = 0.61$) by dietary CP concentration. Phosphorus intake (g/d; $P = 0.02$), fecal P (g/d; $P = 0.04$), and urinary P (g/d; $P = 0.01$) increased linearly as dietary CP increased, reflecting changes in diet composition with increasing CP concentrations. As dietary urea levels increased, urinary N (g/d; $P = 0.04$), UUN (g/d; $P = 0.01$), and apparent N absorption (g/d; $P = 0.04$) increased linearly, but P intake (g/d; $P = 0.10$) and urinary P (g/d; $P = 0.02$) decreased linearly. No interactions were observed between SP and dietary treatments for most variables. Evaluation of SP means, however, showed that as days on feed increased, fecal N (g/d; $P = 0.01$), urinary N (g/d; $P < 0.01$), UUN (g/d; $P < 0.01$), apparent absorption of N (g/d; $P < 0.01$), SUN (mg/dL; $P < 0.01$), and urinary P (g/d; $P < 0.01$) increased linearly, whereas retained N (g/d) decreased linearly ($P < 0.01$) with increasing days on feed. These data suggest that changes in dietary CP and urea levels, as well as stage of the feeding period, markedly alter N and P utilization by feedlot cattle.

Key words: beef cattle, crude protein, feedlot, nitrogen, phosphorus, urea

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INTRODUCTION

The large number of concentrated animal feeding operations in the United States has raised concerns about environmental issues related to air and water pollution. Nutrients excreted in feces and urine have the potential to runoff to surface water, percolate through the soil, accumulate in soil, or volatilize into the atmosphere. The nutrients of primary environmental concern to cattle feeders are N and P (Vasconcelos et al., 2007). Nitrogen excreted in the feces and urine can be lost as ammonia, potentially affecting air quality. Low N:P ratios in feedlot manure, caused by a combination of ammonia losses and excess excretion of P, can limit its value as a fertilizer and may adversely affect soil and water quality as a result of P accumulation in soils and N and P runoff from croplands (Sharpley et al., 1998).

The dietary concentration and source of N and P directly affect their excretion in feces and urine (Vasconcelos et al., 2007). Based on animal requirements, there is potential to decrease dietary concentrations of N and P in beef feedlot diets compared with current nutri-

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tional practices (Gleghorn et al., 2004), but the ability to make changes might be limited by feedstuffs available in a given geographical area. Nonetheless, within practical constraints, formulating diets to minimize nutrients fed to feedlot cattle could potentially minimize not only the nutrients excreted, but also minimize the environmental impact (Cole et al., 2005; Todd et al., 2006; Vasconcelos et al., 2007).

The objective of this study was to determine the effects of 3 dietary CP concentrations with 3 supplemental urea levels arranged in a 3 × 3 factorial on N and P retention and excretion, and serum urea N (**SUN**) concentrations of feedlot steers fed steam-flaked corn-based diets and sampled at different stages of the finishing period.

MATERIALS AND METHODS

All procedures involving live animals were approved by and conducted within the guidelines of the Cooperative Research, Education, and Extension Team Animal Care and Use Committee (Texas Agricultural Experiment Station, USDA-ARS, and West Texas A&M University) and the Texas Tech University Animal Care and Use Committee.

Seventy crossbred steers (British and British × Continental) were purchased from a commercial order-buyer and transported to the USDA-ARS-Conservation and Production Research Laboratory feedlot in Bushland, TX. On arrival, steers were weighed, vaccinated with an infectious bovine rhinotracheitis, parainfluenza-3, bovine viral diarrhea, bovine respiratory syncytial virus modified-live vaccine (Titanium 5, Agri-Labs, Des Moines, IA), and a *Clostridium chauvoei-septicum-novyi-sordelli-perfringens* types C and D bacterin toxoid (Vision 7 with SPUR, Intervet, Millsboro, DE), treated with ivermectin for internal and external parasite control (Ivomec, Merck & Co., Rahway, NJ), and treated, based on individual BW, with tilmicosin phosphate (Micotil, Elanco Animal Health, Greenfield, IN; 10 mg/kg of BW subcutaneously) to decrease respiratory disease. Steers were fed sorghum sudangrass hay for 4 wk and observed daily for signs of morbidity. During this time, 3 steers died as a result of respiratory disease. At the end of the 4-wk period, steers were weighed, and the lightest 34 steers were shipped approximately 200 km to the Texas Tech University Burnett Center at New Deal, TX; the heaviest 32 steers remained at Bushland.

At each location, 27 steers were used in a randomized complete block design with a 3 × 3 factorial arrangement of treatments. Steers were halter-trained and fed a high-roughage diet for a 4-wk period. Following the halter-training period, steers were blocked by BW and allocated to 3 pens (9 steers/pen). Steers were allotted randomly within a block to 1 of 9 treatments (3 steers/treatment at each location). Treatments consisted of 3 formulated dietary CP concentrations (11.5, 13.0, and 14.5% of DM) and 3 concentrations of supplemental urea (100, 50, and 0% of supplemental CP from urea). Supplemental CP was supplied by urea, a 50:50 blend (N basis) of urea and cottonseed meal (**CSM**), or CSM alone (100, 50, and 0% supplemental urea treatments, respectively). Dietary treatments were implemented following a 30-d, 3-step grain adaptation period accomplished by replacing alfalfa hay with steam-flaked corn at 10% increments until the finishing diet was attained (Table 1). Body weight was recorded, and steers were implanted with Synovex-S (Fort Dodge Animal Health, Overland Park, KS; 20 mg of estradiol benzoate and 200 mg of progesterone) on d 0. On d 70 steers were reimplanted with Revalor-S (Intervet Inc.; 120 mg of trenbolone acetate and 24 mg of estradiol). The initial average BW of the steers was 315.0 ± 3.2 kg at location 1 (Bushland, TX) and 353.2 ± 8.4 kg at location 2 (New Deal, TX). Between sampling periods (**SP**), steers at location 1 were individually fed once daily in Calan (American Calan, Northwood, NH) electronic gate feeder pens with free access to water. At location 2, steers were initially housed in individual soil-surfaced pens where they also had access to water and were fed daily, but the steers were moved to concrete, slotted-floor pens (1.5 m × 2.4 m; 3 steers/pen) 1 wk after the first SP. Because only 9 metabolism stalls were available at a time, 3 blocks corresponding to heavy (group 1), intermediate (group 2), and light (group 3) BW groups of 9 steers each were used in each SP at different times. During each of the 3 SP, group 1 was collected first, followed by groups 2 and 3, respectively. Steers were fed the experimental diets for a total of 146, 154, and 162 d for groups 1, 2, and 3 at location 1, and for 151, 159, and 167 d for groups 1, 2, and 3 at location 2, respectively. At location 1, steers in groups 1, 2, and 3, respectively, were housed in tie stalls for the first SP from d 14 to 24, 21 to 31, and 28 to 38; d 77 to 84, 85 to 92, and 93 to 100 for the second SP; and from d 139 to 146, 147 to 154, and 155 to 162 for the third SP. At location 2, the corresponding dates of SP were from d 14 to 25, 21 to 32, and 28 to 39; d 80 to 87, 88 to 95, and 96 to 103; and d 144 to 151, 152 to 159, and 160 to 167 for the first, second, and third SP, respectively. During each SP, steers were housed in indoor individual tie stalls [1.16 m × 2.38 m at location 1 (indoor), and 1.27 m × 2.57 m in location 2 (covered shed)]. Each steer was restrained using a halter that was attached to a ring, which moved freely on a chain spanning the width of each stall. The first SP consisted of a 5-d stall adjustment period and a 5-d total urine and partial fecal collection. The second and third SP consisted of a 2-d tie stall adjustment period and a 5-d total urine and partial fecal collection. Total fecal collection was not possible in these tie stalls, but use of these stalls allowed for DMI to be greater than is often the case in traditional metabolism stalls. The adjustment period was decreased from 5 to 2 d to prevent a decrease in DMI when steers were housed in the tie stalls and because the steers were accustomed to the stalls after the first SP. Unshrunk BW and venous blood samples were obtained at the beginning and end of each SP. The average final BW after the third SP was 507.3 ± 13.0 kg at location 1 and 499.8 ± 9.5 kg at location 2.

Feed refusals were collected daily before 0730 h, weighed, and a representative subsample was collected and composited for each steer. Steers were fed once daily (at approximately 0730 h) during the SP. Feed intake was adjusted daily, if necessary, to limit feed refusals to less than 200 g/d. Feed grab samples were collected daily before feeding and composited for each steer for the 2 d before and 3 d after d 1 of fecal and urine collection. Total urine was collected before 0800 h daily during each SP. A rubber urine pouch attached to the ventral portion of the abdomen via a harness was maintained with a constant vacuum to allow collection of urine into a 20-L polypropylene urine collection reservoir (Nasco Farm & Ranch, Fort Atkinson, WI). On the first day of urine collection, urine that was not acidified was collected for approximately 4 h for an in vitro ammonia emission study (Cole et al., 2005). Subsequently, urine was acidified to pH <4.0 by adding 200 mL of 30% (vol/vol) HCl to the collection reservoir at the start of each urine collection day. Urine volume was measured daily, and 10% aliquots were collected and composited for each steer for all 5 d within a SP. The composited sample was mixed thoroughly, and a subsample was obtained and stored at −20°C for later analysis of total N and P and urinary urea N (**UUN**). Samples of feces were obtained from individual metabolism stalls at 0730 and 1600 h daily and mixed thoroughly to obtain a representative sample. A 500-g sample was collected daily, composited for each steer for the entire 5-d collection period, and 2 subsamples (1 kg and 500 g) were stored at <−4°C. Blood samples (approximately 10 mL) were collected via jugular venipuncture using evacuated serum separator tubes, allowed to clot for 2 h at room temperature, and then centrifuged for 30 min at 5,000 × *g*. An approximate 3-mL aliquot of blood serum was obtained, transferred to a 5-mL transport tube, and stored at <−4°C for later analysis of SUN.

Composited feed, orts, and feces samples were dried at 60°C in a forced-draft oven for 48 h to determine DM. Samples were then ground in a Wiley Mill (Thomas-Wiley Laboratory Mill Model 4, Swedesboro, NJ) to pass a 1-mm screen. Composited feed, orts, and feces were ashed at 550°C for 12 h to determine OM (AOAC, 1990) and were analyzed for NDF using techniques developed by Goering and Van Soest (1970) as modified by Vogel et al. (1999). At location 1, feed, orts, and feces also were analyzed for indigestible NDF as an internal marker for determination of total fecal output. Indigestible NDF and NDF analyses were determined with an Ankom II Daisy fermenter and an Ankom200 Fiber Analyzer (Ankom Technol. Corp., Fairport, NY). At location 2, feed, orts, and fecal samples were analyzed for AIA using the procedure by Van Keulen and Young (1977) as an internal marker for determination of total fecal output.

Feed, orts, feces, and urine samples were analyzed via colorimetric methods for total N and total P. Wet nutrient digestion was performed on samples using a Tecator Block Digestor (Fisher Scientific, Pittsburgh, PA) with 250-mL digestion tubes. After digestion, a 45-mL sample was saved for total N and P analysis. Total N and total P were determined using a flow-injection autoanalyzer (Lachat Instruments, Milwaukee, WI; method 10–107–06–2-E for N, and method 15–115–01–1-B for P). Serum urea N and UUN were determined using the Sigma Diagnostics-Urea Nitrogen Procedure No. 640 (Sigma-Aldrich, St. Louis, MO), slightly modified by forming a calibration curve with standards containing 0, 7.5, 15, and 30 mg of urea N/dL, using a Hewlett Packard 8453 UV-visible spectrophotometer (Agilent Technologies, Palo Alto, CA).

Statistical Analyses

Data were first tested for location × treatment interactions using an ANOVA (GLM procedures of SAS, SAS Inst. Inc., Cary, NC). Crude protein × supplemental urea level × location interactions were observed ($P \leq 0.02$) only for SUN concentrations, urine output (L/d), and fecal P (g/d). Crude protein × location interactions were observed ($P \leq 0.03$) for urinary N (g/d) and fecal P (g/d). Supplemental urea level × location interactions were observed ($P \leq 0.01$) for fecal output (g/d), fecal N (g/d), and fecal P (g/d). Evaluation of simple-effect means suggested that the CP concentration × location and supplemental urea level × location interactions reflected changes in magnitude of treatment responses and not differences in ranking of treatments and, thereby, did not preclude evaluation of the main effects averaged over locations. Therefore, data were pooled over the 2 locations and analyzed as a randomized complete block design with a 3 × 3 factorial arrangement of treatments with repeated measures (SP) using mixed models (MIXED procedure of SAS) with steer as the experimental unit. The model statement for SUN and N and P balance data included CP concentration, urea level, location, and all CP concentration × urea level × location interactions. Block nested within location, location, and location × CP concentration × urea level were included in the random statement. The subject of the repeated measures was defined as steer nested within SP. The compound symmetry covariance structure provided the best fit for these analyses as determined by Akaike information criterion and Schwarz Bayesian criterion values. Orthogonal contrasts were used to determine linear and quadratic effects of dietary CP concentration and level of supplemental CP supplied by urea (spacing of coefficients was based on formulated values) and also to determine the effects of SP on variables across all treatments. Results were considered significant if $P < 0.05$, with tendencies identified when the significance was between 0.05 and 0.10.

Table 1. Composition of finishing diets fed to beef steers at locations 1 and 2 (DM basis)

Item	11.5% CP						13.0% CP						14.5% CP					
	0% urea		50% urea		100% urea		0% urea		50% urea		100% urea		0% urea		50% urea		100% urea	
Location	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Ingredient, %																		
Corn, steam-flaked	75.9	76.69	77.84	78.51	79.8	79.84	71.25	72.43	75.22	76.13	79.12	79.11	66.75	68.24	72.7	73.87	78.58	78.37
Alfalfa, chopped	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Molasses	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Fat	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Urea	—	—	0.26	0.27	0.52	0.5	—	—	0.53	0.57	1.08	1.04	—	—	0.8	0.87	1.62	1.58
Cottonseed meal	4.1	3.81	2	1.72	—	—	8.5	7.97	4.25	3.6	—	—	12.8	12.12	6.4	5.46	—	—
Calcium carbonate	1	—	0.9	—	0.8	—	1.25	0.1	1	—	0.8	—	1.45	0.14	1.1	0.87	0.8	—
Dicalcium, phosphate	—	—	—	—	—	—	—	—	—	0.2	—	0.35	—	—	—	0.3	—	0.55
Supplement[1,2]	2	2.5	2	2.5	2	2.5	2	2.5	2	2.5	2	2.5	2	2.5	2	2.5	2	2.5
Chemical composition,[3] %																		
DM	84.85		84.58		84.96		85.03		84.93		84.5		85.15		84.9		84.83	
CP	10.41		10.63		10.96		11.73		11.52		11.7		12.81		13.33		12.72	
P	0.28		0.26		0.28		0.31		0.29		0.26		0.35		0.31		0.27	
NDF	13.56		13.16		14.23		13.84		14.25		13.16		14.91		13.26		13.03	
DIP[4]	5.5		5.8		6.1		6.4		7		7.7		7.3		8.2		9.3	

[1]Supplement for location 1 contained: 4.81% Ca; 0.99% P; 2.52% NaCl; 0.52% Mg; 1.27% K; 0.62% S; 1.05% Na; 266 mg/kg of Mn; 355 mg/kg of Zn; 508 mg/kg of Fe; 114 mg/kg of Cu; 0.76 mg/kg of Se; 1.16 mg/kg of Co; 34.82 mg/kg of I; 4,000 IU of vitamin A/kg; 30 IU of vitamin E/kg; and 500 IU of vitamin D/kg of DM. All diets contained 30 mg/kg of Rumensin and 11 mg/kg of Tylan (Elanco Animal Health, Indianapolis, IN).

[2]Supplement for location 2 contained: 16.34% Ca; 0.21% P; 12.00% NaCl; 2.9% Mg; 4.05% K; 1.86% S; 4.8% Na; 1,606 mg/kg of Mn; 3,001 mg/kg of Zn; 2,071 mg/kg of Fe; 400 mg/kg of Cu; 2 mg/kg of Se; 8.10 mg/kg of Co; 20 mg/kg of I; 88,000 IU of vitamin A/kg; and 700 IU of vitamin E/kg of DM. All diets contained 33 mg/kg of Rumensin and 11 mg/kg of Tylan (Elanco Animal Health).

[3]Based on laboratory analyses.

[4]Degradable intake protein (DIP) calculated from NRC (1996) tabular values.

Table 2. Effect of increasing CP concentration on daily N and P balance in beef steers consuming high-concentrate diets averaged across 3 sampling periods

Item[1]	CP concentration[2]			SE[3]	Contrast[4]	
	Low	Intermediate	High		L	Q
DMI, kg/d	6.6	6.9	6.6	0.19	0.81	0.04
Fecal output, g of DM/d	1,178	1,250	1,273	254	0.23	0.63
Urine output,[5] L/d	5.4	7.0	5.8	1.15	0.67	0.05
Nitrogen						
Intake, g/d	112.38	131.05	141.83	3.2	<0.01	0.08
Fecal, g/d	35.13	38.53	40.35	6.04	0.03	0.51
Urine,[5] g/d	38.12	55.25	59.84	15.25	<0.01	<0.01
UUN,[5] g/d	26.51	42.88	49.75	6.2	<0.01	0.01
Apparent absorption, g/d	77.19	92.65	101.43	8.7	<0.01	0.16
Apparent absorption, % N intake	68.4	70.1	71.2	5.6	0.17	0.74
Retained, g/d	39.09	37.42	41.51	24.0	0.61	0.55
SUN, mg/dL	7.46	9.45	10.98	1.24	<0.01	0.42
Phosphorus						
Intake, g/d	18.04	20.29	21.79	2.12	0.02	0.57
Fecal,[5] g/d	7.29	8.56	9.67	1.7	0.04	0.78
Urine,[5] g/d	2.48	3.64	3.96	0.8	0.01	0.19
Apparent absorption,[5] g/d	10.70	11.73	12.12	3.7	0.26	0.68
Apparent absorption, % P intake	58.0	55.8	51.1	13.9	0.14	0.85
Retained, g/d	8.21	8.08	8.17	2.9	0.97	0.90

[1]Actual CP concentrations based on chemical analyses were 10.67, 11.65, and 12.95% for the low, intermediate, and high CP treatments, respectively.

[2]SUN = serum urea N; UUN = urinary urea N.

[3]Standard error of treatment means, n = 18 steers/treatment.

[4]*P*-value for linear and quadratic effects of CP concentration.

[5]Crude protein concentration × supplemental urea level interaction, $P < 0.10$.

RESULTS AND DISCUSSION

Diets

Composition of the experimental diets is presented in Table 1. Crude protein concentrations were less than formulated values because the corn used in these studies had an average CP content of 8%, but the diets were formulated based on corn having a CP content of 9%. Therefore, the terms high CP, intermediate CP, and low CP will be used for description of treatments for the remainder of the discussion instead of the formulated or analyzed values. Phosphorus concentrations were more variable than expected in all diets, which was likely a result of difficulty in obtaining representative samples of the finished feed. Based on similar problems in other experiments at our laboratories, we believe settling of mineral components occurred when samples were composited for analysis.

Nitrogen Metabolism and Serum Urea N

CP Concentration. Daily N intake increased linearly (g/d; $P < 0.01$) as dietary CP concentration increased, resulting in a linear increase in total fecal N (g/d; $P = 0.03$), urinary total N (g/d; $P < 0.01$), and UUN excretion (g/d; $P < 0.01$) by steers (Table 2). The increase in urinary N as a result of the increase in total N intake agrees with previous reports (Greathouse et al., 1974; Hoffman et al., 2001; Ludden et al., 2002). Apparent N absorption (g/d) increased ($P < 0.01$) with increasing CP concentrations. Nitrogen retention (g/d), however, was not affected by CP concentration ($P = 0.61$). Studies with sheep have shown increased N retention when feeding diets with greater CP concentration (g/d; Cole, 1999). In the present study, N retention might have not been increased because CP requirements were met or because other factors [i.e., intake of degradable intake protein (**DIP**) or quality of undegradable intake protein (**UIP**)] may have been involved because cattle have different needs for protein of different degradability during various periods of the finishing phase (Klopfenstein et al., 2002).

Using data from the present study, Cole et al. (2005) observed that as the formulated CP concentration in the diet increased from 11.5 to 14.5%, in vitro daily ammonia emissions increased 60 to 200%, likely because of the increased urinary N excretion observed in the present study. Cole et al. (2005) also observed that, as days on feed increased, in vitro ammonia emissions increased, with potential ammonia losses highly correlated to urinary N (mg; $r^2 = 0.69$), UUN (mg; $r^2 = 0.58$) excretion, SUN concentration (mg/100 mL; $r^2 = 0.52$), and intake of degradable protein N (g/d; $r^2 = 0.23$). Data from Cole et al. (2005) along with data from the present experiment support that CP concentration affects daily ammonia losses. Cole et al. (2005) also noted that it is important that diets with decreased CP concentration not affect performance, or total ammonia emissions could be increased because animals would require more days on feed to reach market weight.

Table 3. Effect of supplemental urea level on mean daily N and P balance by beef steers consuming high-concentrate diets averaged across 3 sampling periods

Item[1]	Supplemental CP from urea,[2] %			SE[3]	Contrast[4]	
	0	50	100		L	Q
DMI, kg/d	6.5	6.9	6.8	0.2	0.09	0.18
Fecal DM, g/d	1,268	1,256	1,197	256.5	0.36	0.72
Urine output,[5] L/d	6.2	6.1	6.0	1.2	0.77	0.95
Nitrogen						
Intake, g/d	123.40	131.55	130.25	3.2	0.09	0.15
Fecal, g/d	39.11	38.46	36.43	6.0	0.21	0.69
Urine,[5,6] g/d	47.88	51.81	53.51	15.25	0.04	0.58
UUN,[5,6] g/ d	36.21	39.34	43.58	6.2	0.01	0.78
Apparent absorption, g/d	84.33	93.09	93.84	8.7	0.04	0.25
Apparent absorption, % N intake	67.7	70.4	71.6	5.6	0.07	0.66
Retained, g/d	36.42	41.28	40.33	24.0	0.47	0.52
SUN, mg/dL	9.19	9.58	9.18	1.3	0.98	0.51
Phosphorus						
Intake, g/d	21.14	20.21	18.77	2.1	0.10	0.82
Fecal,[5] g/d	8.41	9.17	7.94	1.7	0.64	0.27
Urine,[5] g/d	4.19	3.01	2.88	0.8	0.02	0.19
Apparent absorption,[5] g/d	12.67	11.04	10.84	3.7	0.15	0.49
Apparent absorption,[5] % P intake	57.6	52.3	55.0	13.9	0.55	0.30
Retained, g/d	8.48	8.03	7.95	2.9	0.61	0.83

[1]SUN = serum urea N; UUN = urinary urea N.
[2]100, 50, and 0% corresponds to the amount of supplemental CP supplied by urea.
[3]SE of treatment means, n = 18 steers/treatment.
[4]P-value for linear and quadratic effects of supplemental urea level.
[5]Crude protein level × supplemental urea level interaction, $P < 0.10$.
[6]Period × supplemental urea levels interaction, $P < 0.10$.

Gleghorn et al. (2004) fed diets formulated to contain the same concentration of CP targeted in the present study (11.5, 13.0, and 14.5% CP) to evaluate performance and carcass characteristics of feedlot cattle. As dietary CP concentration increased from 11.5 to 14.5%, ADG increased quadratically for the overall feeding period. The maximum ADG for the entire feeding period occurred with a CP concentration of 13% (1.71 kg/d), compared with 11.5 (1.65 kg/d) and 14.5% CP (1.67 kg/d; Gleghorn et al., 2004). Cole et al. (2005) compared results with data from Gleghorn et al. (2004) and from the present study to conclude that, with steam-flaked corn-based diets such as used in these studies, the actual CP requirement for optimal performance and maximal N retention is likely between 11.5 and 13% CP.

For samples taken at the beginning and end of each SP, SUN concentrations of steers increased linearly ($P < 0.01$) as dietary CP concentration increased (Table 2). The observed increase in SUN concentrations in relation to increased dietary CP concentration agrees with other observations in the literature (Preston et al., 1965; Cole, 1999; Vasconcelos et al., 2006). This effect presumably reflects less efficient total N utilization by steers, which is likely a result of an excessive supply of dietary CP. Johnson and Preston (1995) proposed that an optimal plasma urea N concentration for protein deposition by beef steers is between 6 and 8 mg/dL. The SUN concentrations for the intermediate CP and high CP treatments in the present study were greater than 8 mg/dL (Table 2), suggesting that these dietary CP concentrations were in excess of requirements.

Supplemental Urea Level. A small linear increase in N intake was observed as supplemental CP supplied by urea increased in the diet ($P = 0.09$), leading to linear increases in total urinary N (g/d; $P = 0.04$) and UUN excretion (g/d; $P = 0.01$; Table 3). This linear increase in urinary total N excretion and UUN excretion is similar to results from sheep fed increasing dietary CP concentrations (Cole, 1999; Ludden et al., 2002), and it is presumably a direct result of replacing a slowly degraded N source (i.e., CSM) with a rapidly degraded N source (i.e., urea). Daily fecal N excretion was not affected ($P = 0.21$) by supplemental urea. Similarly, Duff et al. (2002) fed supplemental CP supplied by all urea, a mixture of urea and soybean meal, or all soybean meal and observed no differences in fecal N excretion by steers. In contrast, Devant et al. (2000) reported that fecal N excretion decreased as ruminal degradability of the supplemental protein source increased. In the present study, apparent N absorption (g/d) increased linearly ($P = 0.04$) as dietary urea level increased, reflecting the previously noted difference in fecal N excretion. Likewise, apparent N absorption (as a % of N intake) increased linearly ($P = 0.07$) as dietary urea level increased. Dietary urea level did not affect ($P = 0.47$) N retention (g/d) in the present study.

Serum urea N concentrations were not affected ($P = 0.98$) by supplemental urea level (Table 3). Results of studies in dairy cattle fed different supplemental

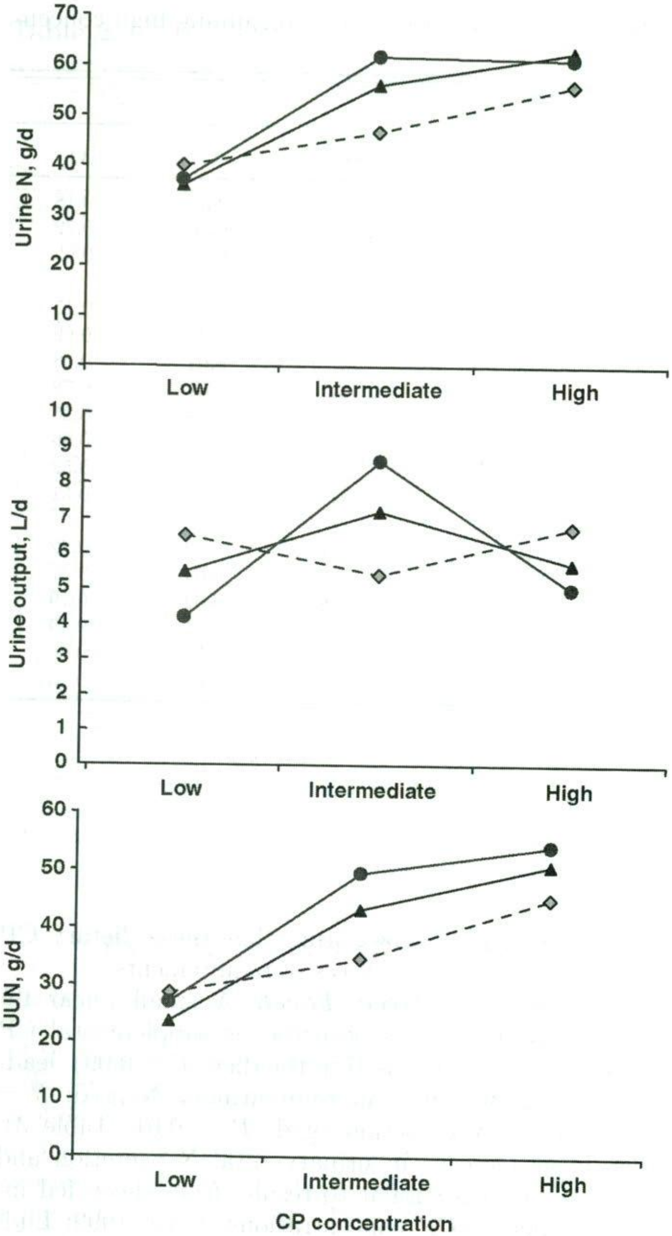

Figure 1. Effects of different formulated CP concentrations (low, intermediate, and high) and urea level [0 (◊), 50 (▲), or 100% (●) of the supplemental CP from urea] on urine output (L/d), urine N (g/d), and urinary urea N (UUN, g/d) of beef steers. Pooled SE of treatment means were 0.64, 2.6, and 2.8 for urine output, urine N, and UUN, respectively. Analyzed CP concentrations were 10.67, 11.65, and 12.95% for the low, intermediate, and high CP treatments, respectively.

protein sources agree with this observation (Rodriguez et al., 1997; Kolver et al., 1998). Other data (Nocek and Polan, 1984; Krzeminski et al., 1985; Spears et al., 1985), however, suggest that ruminant animals fed supplemental CP with a high ruminal degradability have greater SUN concentrations than those fed supplemental N sources with less ruminal degradability.

Interactions. Crude protein concentration × urea level interactions were observed for urine output (g/d; $P < 0.01$), urinary N (g/d; $P < 0.01$), and UUN (g/d; $P = 0.04$; Figure 1). Data presented in Figure 1 indicate that steers fed the intermediate CP diet had greater ($P < 0.01$) urine output and urine N excretion when fed the diet containing 100% of supplemental N from urea compared with steers fed the other dietary treatments. Increasing dietary concentrations of CP for steers fed the 100% supplemental urea diet resulted in increased ($P < 0.01$) quantities of UUN. Data presented in Figure 2 illustrate the interaction between supplemental urea level and collection period for urinary N excretion (g/d; $P = 0.03$), with greater ($P < 0.01$) urinary N in SP 3 than in SP 1 and 2 for all sources of supplemental CP. This finding was likely caused by a decrease in N requirements later in the feeding period, which resulted in increased urinary N excretion. In SP 3, urinary N excretion (g/d) was greater for the treatments, with a greater percentage of urea as the source of supplemental CP. This result was likely caused by requirements for proteins of different degradability (DIP and UIP) during various periods of the feeding period. During the initial stages of the feeding period, young cattle have greater need for UIP to meet their MP requirement (Klopfenstein et al., 2002). It could be challenging, however, to meet protein and NPN requirements of both ruminal microbes and the ruminant animal, accounting for the different types of protein required during the entire feeding period. A tendency for an interaction between supplemental urea level and collection period also was observed for SUN (mg/100 mL; $P = 0.09$; Figure 2). Serum urinary N concentrations were greater ($P < 0.01$) in SP 3 than SP 1 and 2, again presumably reflecting decreased N requirements as days on

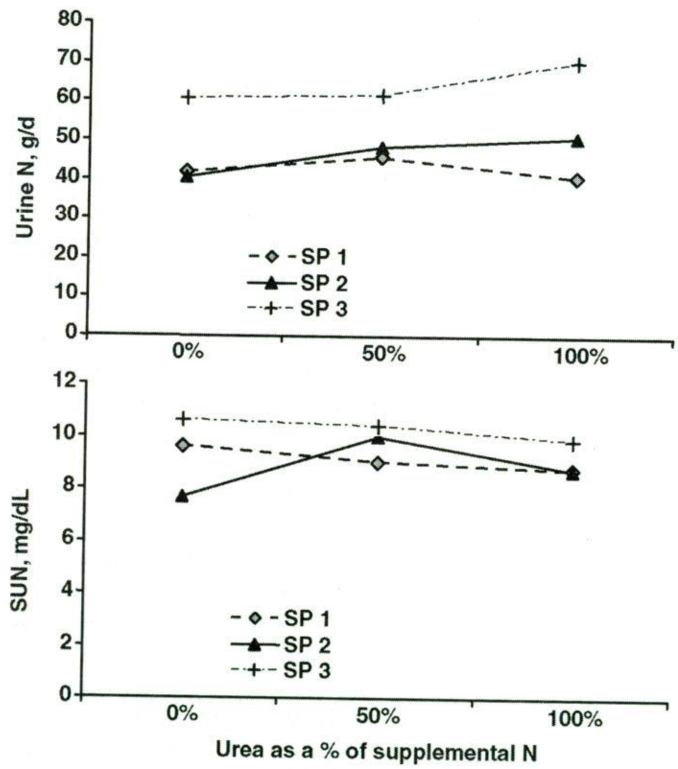

Figure 2. Effects of urea level (0, 50, or 100% of supplemental CP from urea) on serum urea N (SUN, mg/dL; measured at the end of the SP) and urine N (g/d) of beef steers during 3 different nutrient balance sampling periods (SP). Pooled SE of treatment means were 0.6, 2.6, and 2.8 for urine SUN and urine N.

Table 4. Nitrogen and P metabolism values for sampling periods 1, 2, and 3 averaged across CP concentrations and urea levels

	Sampling period[2]				Contrast[4]	
Item[1]	1	2	3	SE[3]	L	Q
DMI, kg/d	6.4	6.7	6.9	0.19	<0.01	0.59
Fecal output, g of DM/d	1,150	1,291	1,260	251.4	0.01	0.02
Urine output,[5] L/d	6.9	5.4	6.0	1.11	0.11	0.02
Nitrogen						
Intake, g/d	120.6	130.2	134.3	3.2	<0.01	0.37
Fecal, g/d	34.42	39.60	39.26	1.3	0.01	0.09
Urine,[5,6] g/d	42.73	46.72	63.74	15.74	<0.01	<0.01
UUN,[5,6] g/d	30.13	36.73	52.27	6.2	<0.01	0.02
Apparent absorption, g/d	86.07	90.66	94.53	8.6	<0.01	0.90
Apparent absorption, % N intake	71.4	69.1	69.2	5.5	0.05	0.22
Retained, g/d	43.29	43.93	30.81	23.9	<0.01	0.02
SUN, mg/dL	8.50	8.74	10.64	1.2	<0.01	0.02
Phosphorus						
Intake, g/d	18.74	20.45	20.93	2.05	0.01	0.43
Fecal,[6] g/d	7.93	8.76	8.83	1.67	0.08	0.38
Urine,[6] g/d	2.63	3.20	4.25	0.84	<0.01	0.50
Apparent absorption,[6] g/d	10.78	11.65	12.11	3.7	0.20	0.82
Apparent absorption,[6] % P intake	56.0	54.7	54.2	13.8	0.56	0.87
Retained, g/d	8.15	8.46	7.85	2.9	0.76	0.59

[1]UUN = urinary urea N; SUN = serum urea N.

[2]For the orthogonal contrasts, mean values were calculated for each collection period. Steers were fed the experimental diets for a total of 146, 154, and 162 d for groups 1, 2, and 3 at location 1 and for 151, 159, and 167 d for groups 1, 2, and 3 at location 2, respectively. At location 1, steers in groups 1, 2, and 3, respectively, were housed in metabolism stalls for the first collection period from d 14 to 24, 21 to 31, and 28 to 38; d 77 to 84, 85 to 92, and 93 to 100 for the second collection period; and from d 139 to 146, 147 to 154, and 155 to 162 for the third collection period. At location 2, the corresponding dates of sampling periods were from d 14 to 25, 21 to 32, and 28 to 39; d 80 to 87, 88 to 95, and 96 to 103; and d 144 to 151, 152 to 159, and 160 to 167 for the first through third collection periods, respectively.

[3]SE of treatment means, n = 27 steers/period.

[4]P-value for linear and quadratic effects of period.

[5]Period × supplemental urea level interaction, $P < 0.10$.

[6]CP level × supplemental urea level interaction, $P < 0.10$.

feed increased. Although no interactions were observed between SP and dietary treatments, fecal (g/d; $P = 0.01$) and urinary (g/d; $P < 0.01$) N excretion increased linearly with increased days on feed (Table 4).

Phosphorus Metabolism

CP Concentration. Results for P balance are presented in Tables 2 and 3. Phosphorus intake (g/d; $P = 0.02$), as well as fecal (g/d; $P = 0.04$) and urinary (g/d; $P = 0.01$) P excretion increased as dietary CP concentration increased. Similar results have been previously observed for fecal P excretion (Challa et al., 1989; Knowlton et al., 2001) and for urinary P excretion (Challa et al., 1989). No differences were observed in apparent P absorption (g/d; $P = 0.26$), apparent P absorption (% of P intake; $P = 0.14$), and retained P (g/d; $P = 0.97$) as CP concentration increased. Conversely, Cole (1999) fed sheep 10.0, 12.5, and 15.0% dietary CP and observed that P retention (g/d) linearly increased as dietary CP concentration increased.

Supplemental Urea Level. As expected, as supplemental CP supplied by urea increased, P intake tended to decrease linearly ($P = 0.10$). This decrease in P intake occurred because of the numerical decrease in P concentration of diets containing supplemental CP from urea. Likewise, urinary P excretion decreased (g/d; $P = 0.02$) with increasing urea level. No effects ($P > 0.10$) of increasing levels of urea were observed on apparent P absorption (g/d or % of P intake) or P retention ($P = 0.61$).

Interactions. Crude protein level × urea level interactions were observed for fecal ($P = 0.06$) and urinary ($P < 0.01$) P excretion and apparent P absorption (% of P intake; $P < 0.01$). These interactions are depicted graphically in Figure 3. Urinary P excretion was greater ($P < 0.01$) for the 100% urea treatment with the high CP diet, which is likely a result of the replacement of CSM by urea. Nonetheless, high concentrations of CP associated with increasing levels of CSM resulted in increased absorption of P. Formulating diets to meet protein requirements with NPN sources, rather than true protein sources, could significantly decrease the P intake of finishing cattle. The urinary P excretion, as a percentage of P intake, was decreased ($P < 0.01$) from 19.8% with 0% urea to 14.9 and 15.3% of P intake with 50 and 100% urea, respectively.

Effects of Days on Feed

Although no treatment × SP interactions were observed for most variables, to illustrate the effect of

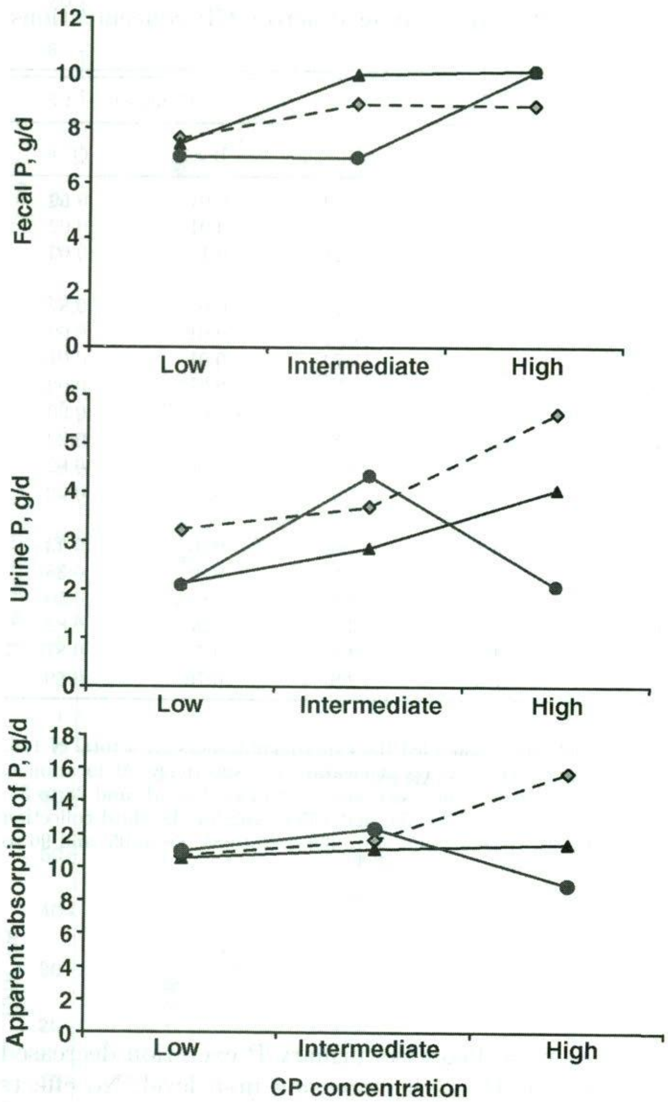

Figure 3. Effects of different formulated CP concentrations (low, intermediate, and high) and urea level [0 (◊), 50 (▲), or 100% (●) of the supplemental CP from urea] on fecal P (g/d), urine P (g/d), and apparent absorption of P (g/d) by beef steers. Pooled SE of treatment means were 0.86, 0.58, 1.30 for fecal P, urine P, and apparent absorption of P, respectively. Analyzed CP concentrations were 10.67, 11.65, and 12.95% for the low, intermediate, and high CP treatments, respectively.

days on feed, data from the present experiment were combined across treatments and presented by period in Table 4. Fecal N (g/d; $P = 0.01$), urinary N (g/d; $P < 0.01$), UUN (g/d; $P < 0.01$), apparent absorption of N (g/d; $P < 0.01$), apparent absorption of N (% of N intake; $P = 0.05$), and SUN ($P < 0.01$) increased linearly during the feeding period. Nitrogen retention (g/d) decreased linearly with days on feed ($P < 0.01$). Urinary (g/d; $P < 0.01$) and fecal (g/d; $P = 0.08$) P excretion also increased linearly during the feeding period. These results support the concept that CP and MP requirements of feedlot cattle change as animals grow and mature, being greater during the initial part when rates of protein deposition are high and decreasing during the later stages of finishing. Feeding a constant concentration of CP in cattle finishing diets (approximately 13.5%) is a common practice in the industry to simplify feed bunk and mill management (Vasconcelos et al., 2007). To conserve N and avoid decreases in animal performance, dietary CP concentrations could be adjusted during the feeding period to more closely meet the nutrient requirements of the animal (e.g., phase feeding; Klopfenstein et al., 2002; Cole et al., 2006; Vasconcelos et al., 2006). Studies conducted with feedlot cattle fed dry-rolled corn (**DRC**) suggest that supplemental protein could be partially or completely withdrawn from finishing diets during the later part of the feeding period with little or no effect on cattle performance (Erickson et al., 1999). Vasconcelos et al. (2006) reported similar results in cattle fed steam-flaked corn (**SFC**)-based diets. Cole et al. (2006), however, conducted a larger study with SFC-based diets and observed that steers changed from a 13.0% to an 11.5% CP diet with 56 d left on feed had less ADG and DMI than steers continuously fed 11.5 or 13% CP diets. Differences in results of phase-feeding studies using DRC- and SFC-based diets likely occur because requirements for DIP in diets containing steam-flaked grains are estimated to be greater than in less fermentable DRC-based diets (Cooper et al., 2002). Data from Vasconcelos et al. (2006) and Cole et al. (2006) also suggest that implanting strategies may affect performance response to phase feeding of cattle fed SFC-based diets.

Concluding Remarks

Results from the present study, along with data from Cole et al. (2005) and Gleghorn et al. (2004), suggest that the actual CP requirement for optimal performance and maximal N retention of finishing steers fed SFC-based diets was between 11.65 and 12.95% CP (based on analyzed CP values; formulated values were 13 and 14.5% CP, respectively). Increasing the proportion of supplemental CP supplied by urea decreased P intake, resulting in a decrease in P excretion; however, it also resulted in increased total urinary N excretion and potential ammonia losses. Decreasing dietary N and P inputs into concentrated animal feeding operations could potentially decrease environmental concerns related to air and water quality. The decrease in dietary CP concentration should not affect performance, or it could possibly lead to increased total ammonia emissions because of an increase in days on feed to reach market weight. Data from Erickson et al. (1999) and Cole et al. (2005) suggest that decreased dietary N inputs during the latter part of the feeding period, achieved for example by phase feeding, could potentially decrease ammonia emissions.

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